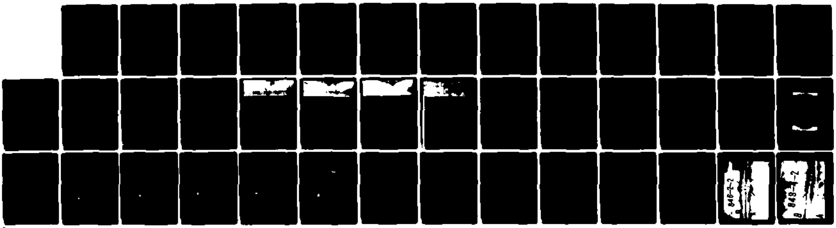
AD-A145 497 DESIGN CONSTRUCTION DEMONSTRATION AND DELIVERY OF AN AUTOMATED NARROW GAP WELDING SYSTEM(U) CRC AUTOMATIC WELDING CO HOUSTON TX 30 SEP 83 CRC-NAV-A/W-8 1/1

UNCLASSIFIED N00600-81-C-E923 F/G 13/10 NL



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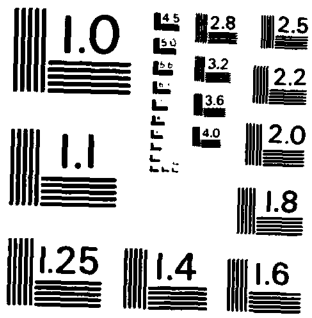


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(1)

CRC REPORT NO. NAV A/W 8

PHASE 4 REPORT

ON

DESIGN, CONSTRUCTION, DEMONSTRATION AND
DELIVERY OF AN AUTOMATED NARROW GAP
WELDING SYSTEM
CONTRACT NO. N00600-81-C-E923

TO

DAVID TAYLOR RESEARCH AND DEVELOPMENT CENTER
DEPARTMENT OF THE NAVY

FROM

CRC AUTOMATIC WELDING
SEPTEMBER 30, 1983

INTRODUCTION

The objective of this program is to design, construct, demonstrate, and deliver an automated, Narrow Gap welding system capable of welding high strength steel plates under shipyard production conditions in the construction of aircraft carriers. The program is being conducted in five phases:

(1) Definition of Requirements

(2) Design of Welder Package

(3) Equipment Construction

(4) Qualification of Process and Equipment

(5) Shipyard Demonstration

Phase I was completed slightly ahead of schedule and the Phase I report, CRC Report No. NAV A/W 1, was submitted November 5, 1981. Phase I was devoted to a thorough review of the requirements that must be met by a shipyard production Automated Narrow Gap welding system (ANGWS).

Phase 2 was completed slightly behind schedule and the Phase 2 report, CRC No. NAV A/W 4, was submitted June 29, 1982. This report covered the detailed design of the Narrow Gap welder. Phase 3 was completed behind schedule and the Phase 3 report CRC No. NAV A/W 7, was submitted March 31, 1983. This report covered the construction of the Narrow Gap Welder.

PHASE 4 QUALIFICATION OF SOFTWARE AND EQUIPMENT

This phase 4 report summarizes the work done from April 1, 1983 through September 30, 1983.

MATERIALS

Preliminary welding was done on 2 1/2 inch thick HY-100 steel plate. The chemical composition and mechanical properties of this plate were not determined.

The process qualification work was done on 2-inch-thick HY-100 plate purchased from Phoenix Steel Corporation. Two plates, 2-by 80-by 252 inch, were purchased. The heat records are shown in Appendix Tables A-1 and A-2. Transverse specimens for charpy vee-notch and dynamic tear testing were machined from the plate material to qualify the plates to "J" specification.

The charpy impact testing was done at Metallon Inc. in Houston, Texas. The dynamic tear testing was done at David Taylor Naval Ship Research and Development Center (DTNSRDC), Annapolis, Maryland. The results of

these base plate tests were as shown below:

TEST	HY-100, HEAT NUMBER 4227G-39	HY-100, HEAT NUMBER 53203-39
Charpy Vee-Notch foot - pounds		
0°F Test Temperature	108, 117, 112, 117,111.5	115,110,111.5, 114
-120°F Test Temperature	72, 63.5, 76.5, 67.5, 68.5	61, 54.5, 73.5, 77, 11.5
Dynamic Tear, foot - pounds		
- 40°F	939.8, 933.5	885.9, 888.4

The backup bars were 1/2" by 1-inch HY-100 material supplied by DTNSRDC. The chemical composition of the backup bar material was not determined.

Initially, 1/16-inch-diameter Airco AX-90 filler wire was used. However, considerable fumes were given off during welding and there was some tendencies to arc instability when using this filler wire. Linde 95, 1/16-inch-diameter, filler wire was substituted and used for the majority of the welding evaluation and for the qualification welds. The nominal composition of the Linde 95 filler wire was as shown below:

Element	Chemical Composition Weight Percent
C	0.04 to 0.06
Mn	1.00 to 1.40
Si	0.30 to 1.40
Ni	1.95 to 2.05
Cr	0.05 to 0.20
Mo	0.40 to 0.50

The shielding gas used throughout these evaluations was 95-5 percent, Argon-CO_2.

EQUIPMENT

The Narrow Gap welding equipment was designed in Phase 2 and constructed in Phase 3 of this contract. Two Narrow-Gap welders were built instead

of the contracted requirement for one machine. A "prototype" model was built to insure the design was correct, several modifications were made. The necessary changes were made to the drawings and a production model was built to the updated drawings. Both models were used for development and testing.

As a result of the work done in Phase 3 to evaluate welding power supplies, a 650-ampere, Miller Delta weld 650 was purchased and used throughout Phase 4.

Preheating was provided by strip heaters. Preheat temperature was determined by a contact pyrometer and by tempilstiks.

EXPERIMENTAL PROCEDURE

Extensive welding trials were conducted during Phase 3 to evaluate the Narrow Gap welder's capability to deposit sound welds in 2 1/2-inch thick HY-100 plate. The preliminary work that was done in Phase 4 was to evaluate the adaptive computer software program and to investigate the weld joint design. The program plan followed was to deposit welds in 2-foot-long HY-100 plates, 2 1/2-inch-thick and modify the software program and joint design as required. Then 5-foot long HY-100 plates, 2 1/2-inch thick, were welded to investigate the consistency of the system. Finally, welds were made in 20-foot-long, 2-inch-thick HY-100 plate

preparatory to the find 20-foot-long qualification weld. The number of welds made during this Phase 4 evaluation were as follows:

Weld Length, Feet	Plate Thickning inches	Number of Welds
2	2 1/2	45
5	2 1/2	43
20	2	4

The filler wire used for all of these welds was 0.0625-inch-diameter. Linde 95 using a shielding gas of 95-5 percent Argon-CO_2. Over 1,500 pounds of filler wire was used for these welding trials.

In addition, 3-welds were deposited in 4-foot long, 4-inch-thick, HY-100 plate. Additional work on the 4 inch thick plate will be required before a procedure can be qualified.

Narrow Gap Welding Adaptive Software Studies

During the welding evaluation, it was determined that a different welding procedure would have to be developed for the root pass than for the fill passes and cap pass. The problem involved in depositing the root pass was the general tendency toward arc instability caused by the spacing between the backing bar and the test plates. In the usual startup procedure, the torch would move to the left until the filler wire touched the top edge of the weld joint, then move to the right until the right sidewall was touched, and then move to the midpoint between these sidewalls . At that point, the welding head

normally would drive down until the filler wire touched the bottom of the joint, move left, and then right, and center in the bottom of the joint and start welding. Because of the Narrow Gap joint configuration, it was practical to determine only the centerline of the weld joint at the top and drive straight down to the bottom of the joint and start welding. To tell the microprocessor that a root pass was desired, the software was modified so that if the welding head moved down more than one-inch the program would automatically select the root pass welding parameters. The first four oscillation sweeps at the start of welding was done under predetermined welding conditions, i.e., wire-feed-speed, voltage, etc. During these four sweeps, the microprocessor was collecting data concerning centerline height and computing the required welding parameters for the remaining root-pass welding.

The adaptive feed-back-control concept is based on detecting the change in arc length and its effects on the voltage-amperage relationship as the sidewall is approached. This requires a minimum of 0.100-inch-high sidewall to track the weld joint. The minimum sidewall height may not be available after the last fill pass because of either overfill or because of a high-low condition in the plate fitup. It was determined that the most practical solution was to allow for a manual, steerable cap pass routine. On the cap pass, the operator uses a remote pendant to position manually the cap pass. There are two control push buttons located on the remote pendant. By activating the "centerline out" or "centerline in" buttons, the torch can be moved 0.025-inch every sweep of the oscillation in either direction. In this manner, the operator can "steer" the path of cap pass.

Additional changes to the software involved the addition of new diagnostic routines to insure proper operation of the computer control, modification of the travel speed algorithms to improve weld pool profiles, and improvement in the initial startup parameters by ramping the arc voltage during the initial startup welding.

Joint Design

The initial welding studies were made using a parallel-sided joint, approximately 3/8 inch-wide. The water-cooled contact-tube assembly is almost 1/4-inch-wide. The minimum oscillation width for tracking is 0.040 inch. Therefore, the contact-tube assembly tended to drive into the sidewall producing a "shorting out" situation before the arc came close enough to the sidewall to detect a sidewall-signal response. To provide some greater clearance, the plates were angled so that the joint opening was about 3/8-inch wide at the root with an included joint opening of approximately 6-8 degrees. A number of welds were made to determine the root opening tolerances that could be welded with a joint included angle of 6-8 degrees. It was determined that the limits on joint opening with the 6-8 degree included angle was 3/8 inch ± 1/8 inch.

It was recognized that cocking or canting the plates to produce the desired opening might not be practical. Subsequent studies were made where the plates were flame-beveled 3-4 degrees to produce a 6-8 degree included angle joint with the plate surfaces flat. Satisfactory welds were made in this manner.

Contact Tips

The service life of the contact tip was of concern during phase 4 of the project. The required tip life was a minimum of 20 feet of weld length so a pass could be deposited without a start-stop. It was established early in Phase 4 that normal copper tips were not satisfactory. Contact tip life was improved with a Tellurium alloy but a 20 foot length was not achieved. Finally, a 6% Tungsten-copper alloy with a 0.078 inch to 0.080 inch hole was found to have a service life in excess of 20 feet.

Qualification Welds

The Narrow Gap welding system developed in this contract is an adaptive-feedback controlled system that senses the edges of the weld joint, tracks the joint, and continuously adjusts the welding parameters, wire-feed speed (amperage), arc voltage, travel speed, and oscillation width as required to maintain a target heat input level and fill height. An upper limit target heat input of 55,000 joules per inch was used. However, cap passes were deposited at about 70,000 joules per inch. Typical welding parameters were as shown below.

Parameter	Typical Values
Wire Feed Speed, ipm	235
Arc Voltage, volts	25 to 28
Travel Speed, ipm	7 to 12

test weld #82 was deposited in 2-inch-thick. 5 feet long, HY-100 plate for preliminary mechanical property testing. The backing bar was removed by flame cutting followed by hand grinding. A back weld was made with the Narrow Gap welding system. The weld was radiographed using an Iridium 192 isotope ultrasonically inspected, and shipped to DTNSRDC for testing. The transverse-weld tensile and dynamic tear properties were determined. A single explosion-bulge plate was prepared and tested at the Naval Ordinance Laboratory at Louisville, Kentucky.

Newport News Shipbuilding, (NNS) personnel were throughly familiar with the Narrow Gap Welder and its operation as a result of numerous trips to CRC during Phase 3. As a result, the 20-foot-long Phase 4 qualification weld was made at CRC with NNS personnel operating the equipment and assisted by CRC personnel. This weld #92 was radiographed, ultrasonically inspected, back welded, and cut into six explosion-bulge plates. The explosion bulge plates were sent to Louisville for testing. The set consisted of two crack starter plates and four conventional bulge plates. A portion of this weld was sent to DTNSRDC for mechanical property testing and another portion was sent to the Columbus Laboratories, Battelle Memorial Institute, Columbus, Ohio, for microhardness determinations and metallographic examination.

RESULTS

The results of the destructive tests performed on preliminary weld #82 are shown in Table 1.

The results of the destructive tests of qualification weld #92 are shown in Table 2. In addition, the explosion bulge report sheets from the Naval Ordinance Station, Louisville, Kentucky and a sample photograph of a crack starter and a conventional bulge, as well as a copy of the Battelle report on hardness, microstructures and macrostructures are in Appendix A-3.

TABLE 1. PRELIMINARY MECHANICAL PROPERTY TESTS

ANGW - 82 MC (CRC)

B.M. - HY-100
F.M. - 100S-1

WELD METAL MECHANICAL PROPERTIES

Specimen No.	Y.S. (Ksi)	T.S. (Ksi)	E.Long (%)	R.A. (%)	DT Ft./Lbs. - 20°F	DT Ft./Lbs. + 30°F
82MC-TB	112.0	120.8	21	69		
82MC-TT	92.8	114.9	25	68		
DB-1					377.1	-----
DT-1					322.6	-----
DB-2					-----	636.6
DT-2					-----	581.6
Spec. Req.	82-110*				300	450

EXPLOSION BULGE

Specimen No.	SHOT NO.	Reduction in ThK (%) SIDE A	Reduction in ThK (%) SIDE B	Dept of Bulge (in) SIDE A	Dept of Bulge (in) SIDE B	COMMENTS
844-Bulge	1-	1.768	2.213	1.340	1.40	- No visible cracks or tears.
	2-	4.125	4.771	2.46	2.55	- No visible cracks or tears.
	3-	7.859	9.394	3.445	3.49	- No visible cracks or tears.
	4-	11.542	13.625	4.060	4.265	- No visible cracks or tears.
	5-	14.489	17.265	4.700	5.025	- Crack B side Tow, 9" center to left, center to Rt 8" penetrates plate within test area.

* Per NAVSEA 05M2 Min. Y.S. 90 Ksi

TABLE 2. QUALIFICATION WELD NO. 92

Yield Strength	108.9	Ksi
Ultimate Tensile Strength	116.7	Ksi
Elongation	22%	
Reduction in Area	70%	
Charpy vee-Notch		
0° F.	71, 80, 69.5	Ft. lbs.
-60° F.	63, 64, 47.5	Ft. lbs.
Dynamic Tear		
0° F.	865.1, 710, 865.4	Ft. lbs.
-60° F.	364, 423, 396	Ft. lbs.

SUMMARY

Preparation for the 20 foot long qualification began when the results of preliminary weld #82 were satisfactory.

The execution of the qualification weld by Newport News Shipbuilding personnel and the successful completion of all non-destructive and destructive testing marked the completion of Phase 4. Phase 5 will begin immediately.

It should be noted that the cracks incurred from explosion bulge testing of conventional and crack starter samples did not penetrate through the thickness of any test plate.

APPENDIX

FORM W-662 R2

PHOENIX STEEL CORPORATION
CLAYMONT, DELAWARE 19703
MATERIAL TEST REPORT

SPECIFICATION MIL-S-16216H (SHIPS) 15 MARCH 1972 (HY-100) Oct. 6

HY-100 Steel

CUSTOMER ORDER NO.

SOLD TO CRC Automatic Welding
3450 Lang Road
Houston, Tx. 77092

MILL ORDER NO.

CAR NO. TRUCK

HEAT NO.	SLAB NO.	CHEMICAL ANALYSIS C	MN	P	S	SI.	CU.	NI.	CR.	MO.	AL	V	TI	YIELD STRENGTH P.S.I.
42276-39	78470 78470	.14	.30	.010	.003	.21	.17	3.40	1.44	.29	.027	.004	NIL	110000 112500
CHEC K ANALYSIS		.14 .14	.30 .30	.009 .011	.004 .004	.20 .20	.17 .18	3.35 3.42	1.40 1.42	.29 .30	.023 .022	.003 .003	.001 .001	LCVN
														L-114-

TRANSVERSE CHARPY (FT-LBS)

0°F 108, 117, 112, 117, 111.5 113.1

-120°F 72, 63.5, 76.5, 67.5, 68.5 69.6

TRANSVERSE DYNAMIC TEAR (FT-LBS) -40°F 939.8, 933.

SUBSCRIBED AND SWORN TO BEFORE ME

THIS 11th DAY OF Oct

Francis A. Maloney
NOTARY PUBLIC

PHOENIX STEEL CORPORATION
CLAYMONT, DELAWARE 19703
MATERIAL TEST REPORT

APPENDIX TABLE A-1

CH 1972 (HY-100) — Oct. 6, 1982 — B. L. NO.

CUSTOMER ORDER NO. 12708

MILL ORDER NO. 52446-39

CAR NO. TRUCK

BEND TEST	HOMOGENITY TEST

MICAL ANALYSIS I.	CU.	NI.	CR.	MO.	AL	V	TI	YIELD STRENGTH P.S.I.	TENSILE STRENGTH P.S.I.	% ELONG. 2"	% ELONG. 8"	RED OF AREA	SIZE
21	.17	3.40	1.44	.29	.027	.004	NIL	110000 112500	120500 125000	22.0 21.0		67.0 69.9	1- 2"x80x252"
20 20	.17 .18	3.35 3.42	1.40 1.42	.29 .30	.023 .022	.003 .003	.001 .001	LCVN @-120 DEG.F.					
								L-114-122-112			BHN	257/237	
RSE CHARPY (FT-LBS)													
	108,	117,	112,	117,	111.5		113.1						
	72,	63.5,	76.5,	67.5,	68.5		69.6						
RSE DYNAMIC TEAR (FT-LBS)						-40°F	939.8, 933.5						

ME

I CERTIFY THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION.

SUPR. OF TESTING, METALLURGICAL DEPT.

PHOENIX STEEL CORPORATION
CLAYMONT, DELAWARE 19703
MATERIAL TEST REPORT

APPENDIX TABLE A-1

(HY-100) Oct. 6, 1982 B. L. NO.

CUSTOMER ORDER NO. 12708

MILL ORDER NO. 52446-39

CAR NO. TRUCK

ANALYSIS											
NI.	CR.	MO.	AL	V	TI	YIELD STRENGTH P.S.I.	TENSILE STRENGTH P.S.I.	ELONG. 2"	ELONG. 8"	RED OF AREA	SIZE
3.40	1.44	.29	.027	.004	NIL	110000 112500	120500 125000	22.0 21.0		67.0 69.9	1- 2"x80x252"
3.35 3.42	1.40 1.42	.29 .30	.023 .022	.003 .003	.001 .001	LCVN @-120 DEG.F.					
						L-114-122-112			BHN 257/237		
PY (FT-LBS)											
17,	112,	117,	111.5		113.1						
3.5,	76.5,	67.5,	68		69.6						
MIC	TEAR	(FT-LBS)		-40°F	939.8, 933.5						

I CERTIFY THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION.

SUPR. OF TESTING, METALLURGICAL DEPT.

PHOENIX STEEL [illegible]
[illegible]
MATERIAL TEST REP[illegible]

SPECIFICATION MIL-S-16216H (SHIPS) 15 MARCH 1972 (HY-100)

HY-100 Steel

SOLD TO CRC Automatic Welding
3450 Lang Road
Houston, Tx. 77092

HEAT NO.	SLAB NO.	C	MN	P	S	SI	CU	NI	[illegible]	[illegible]	AL	V
		CHEMICAL ANALYSIS										
42276-39	78470 78470	.14	.30	.010	.003	.21	.17	3.40	1.44	.29	.027	.004
CHECK ANALYSIS		.14 .14	.30 .30	.009 .011	.004 .004	.20 .20	.17 .18	3.35 3.42	1.40 1.42	.29 .30	.023 .022	.003. .003

TRANSVERSE CHARPY (FT-LBS)

0°F 108, 117, 112, 117, 111.[illegible]

-120°F 72, 65.5, 76.5, 67.5, [illegible]

TRANSVERSE DYNAMIC TEAR (FT-LBS) [illegible]

SUBSCRIBED AND SWORN TO BEFORE ME

THIS 11th DAY OF Oct

Frances A. Maloney

NOTARY PUBLIC

IX STEEL CORPORATION
IONT, DELAWARE 19703
ERIAL TEST REPORT

PLATE 2

APPENDIX TABLE A-2

Dec. 8, 1982 B. L. NO.

CUSTOMER ORDER NO. 12708

MILL ORDER NO. 52446-39

CAR NO. TRUCK

BEND TEST	HOMOGENITY TEST

MO.	AL	V	TI	YIELD STRENGTH P.S.I.	TENSILE STRENGTH P.S.I.	% ELONG. 2"	% ELONG. 8"	RED OF AREA	SIZE
.48	.027	.002	.001	112000 114000	127000 131500	23.0 21.0		63.8 63.5	1- 2"x80x252"
.52 .51	.029 .025	.002 .002	.001 .001						
QUENCHED, THEN TEMPERED ABOVE 1150 Deg.F., TO MEET									
VG. 12.4									
66.5									
35.9, 888.4									

I CERTIFY THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION

SUPR. OF TESTING METALLURGICAL DEPT.

PHOENIX STEEL CORPORATION
CLAYMONT, DELAWARE 197[illegible]
MATERIAL TEST REPORT

[illegible]ATION MIL-S-16216H (SHIPS) 15 MARCH 1972 (HY-100) ______ Dec

______ HY-100 Steel ______ CUSTOMER [illegible]

SOLD TO CRC Automatic Welding
3450 Lang Road
Houston, Tx. 77092

MILL ORDER [illegible]

CAR NO. T

HEAT NO.	SLAB NO.	C	MN	P	S	SI.	CU.	NI.	CR.	MO.	AL	V	TI	ST[illegible]
5[illegible]3-39	80863 80863	.18	.24	.009	.008	.29	.24	2.89	1.48	.48	.027	.002	.001	112 114
		LCVN @-120 DEG.F.				BHN								
53203-39	80863	L-100-99-104				257/257								
CHECK ANALYSIS 53203-39		.18 .18	.26 .25	.012 .012	.010 .010	.31 .30	.21 .21	2.70 2.73	1.54 1.52	.52 .51	.029 .025	.002 .002	.001 .001	

AUSTENITIZED AT 1575 +/- 25 F AND WATER QUENCHED, THEN TEMPERE[illegible]
THE ABOVE PROPERTIES

TRANSVERSE IMPACTS (FT-LBS)		AVG.
0°F	115, 110, 11[illegible].5, 11[illegible].5, 114	112.4
-120°F	61, 54.5, 7[illegible].5, 72, 71.5	66.5
TRANSVERSE DYNAMIC TEAR (FT-LBS) -40°F		885.9, 888.4

SUBSCRIBED AND SWORN TO BEFORE ME

THIS ______ DAY OF ______

______
NOTARY PUBLIC

PHOENIX STEEL CORPORATION
CLAYMONT, DELAWARE 19703
MATERIAL TEST REPORT

ATION MIL-S-16216H (SHIPS) 15 MARCH 1972 (HY-100) — Dec. 8, 1982

HY-100 Steel — CUSTOMER ORDER NO. 12708

LD TO CRC Automatic Welding — MILL ORDER NO. 52446-39
3450 Lang Road
Houston, Tx. 77092 — CAR NO. TRUCK

HEAT NO.	SLAB NO.	C	MN	P	S	SI.	CU.	NI.	CR.	MO.	AL	V	TI	YIELD STRENGTH P.S.I.	TENSILE STRENGTH P.S.I.	% 2"
3-39	80863 80863	.18	.24	.009	.008	.29	.24	2.89	1.48	.48	.027	.002	.001	112000 114000	127000 131500	23.0 21.0
		LCVN	0-120 DEG.F.			BHN										
203-39	80863	L-100-99-104				257/257										
HECK ANALYSIS 3203-39		.18 .18	.26 .25	.012 .012	.010 .010	.31 .30	.21 .21	2.70 2.73	1.54 1.52	.52 .51	.029 .025	.002 .002	.001 .001			

AUSTENITIZED AT 1575 +/- 25 F AND WATER QUENCHED, THEN TEMPERED ABOVE 1150 De
THE ABOVE PROPERTIES

TRANSVERSE IMPACTS (FT-LBS) — AVG.
0°F 115, 110, 111.5, 111.5, 114 — 112.4

-120°F 61, 54.5, 73.5, 72, 71.5 — 66.5

TRANSVERSE DYNAMIC TEAR (FT-LBS) -40°F 885.9, 888.4

SUBSCRIBED AND SWORN TO BEFORE ME

THIS ________________ DAY OF ________________

____
NOTARY PUBLIC

CERT
CONTA

PHOENIX STEEL CORPORATION
CLAYMONT, DELAWARE 19703
MATERIAL TEST REPORT

PLATE 2

APPENDIX TABLE A-2

K-100) Dec. 8, 1982 B. L. NO.

CUSTOMER ORDER NO. 12708

MILL ORDER NO. 52446-39

CAR NO. TRUCK

BEND TEST	HOMOGENITY TEST

ALYSIS						YIELD STRENGTH P.S.I.	TENSILE STRENGTH P.S.I.	% ELONG.		RED OF AREA	SIZE
	CR.	MO.	AL	V	TI			2"	8"		
39	1.48	.48	.027	.002	.001	112000 114000	127000 131500	23.0 21.0		63.8 63.5	1- 2"x80x252"
3	1.54 1.52	.52 .51	.029 .025	.002 .002	.001 .001						
	WATER	QUENCHED,		THEN	TEMPERED ABOVE 1150 Deg.F.,					TO MEET	
		AVG. 112.4									
		66.5									
	40°F	885.9, 888.4									

I CERTIFY THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION.

SUPR. OF TESTING, METALLURGICAL DEPT.

Battelle
Columbus Laboratories
[illegible] Avenue
Columbus, Ohio 43201
Telephone (614) 424-6424
[illegible]

October 26, 1983

Mr. Brian Laing
CRC Automatic Welding
3450 Lang Road
Houston, TX 77092

Dear Brian:

This letter presents the results of our metallographic examination of the 20-foot-long demonstration weld in HY-100 steel plate.

Macroexamination

A section was cut from the CRC sample. This section was located about half way along the sample length so that it would be as far as possible from the sample edges. Sectioning was by a band saw using oil-water emulsion coolant. The section then was ground and polished for metallographic examination.

A photomacrograph of this section is in Figure 1. The weld is sound throughout. No porosity, lack of fusion, inclusions, or cracks were present. The pore-like feature in the right heat-affected zone of the second fill pass is an artifact and was not present in the actual specimen. The cap pass and/or the last fill pass are unbalanced to the left side of the joint. The arc oscillation possibly was biased in this direction.

The width of the heat-affected zone was measured at several locations. The measured widths were:

	Heat-Affected Zone Width, inch	
	Left Side	Right Side
At top surface	0.095	0.116
1/16 inch below top surface	0.238	0.152
Mid thickness	0.112	0.092
1/16 inch above bottom surface	0.167	0.208
At bottom surface	0.078	0.110

Hardness Measurements

Microhardness (Knoop 500 gram) traverses were made across the width of the weld joint at five locations. These are shown by the arrows and accompanying numbers in Figure 1. Traverses 1 and 5 were made at a location 1/16 inch below the top and bottom surfaces respectively, of the specimen. At this location, measurements were made in the untempered weld metal of the cap and root passes and their heat-affected zones. Traverses 2 and 4 were made at a location approximately 1/8 inch below the bottoms of the cap and root passes. Traverse 3 was made at the middle of the specimen. Each traverse included at least three measurements in each base metal, six measurements in each heat-affected zone, and five measurements in the weld metal. The spacing

between the heat-affected-zone measurements was 0.010 inch. The weld-metal measurements were equally spaced across the width of the weld metal. Base metal measurements were made approximately 0.25 inch from the edge of the heat-affected zone and were spaced at 0.010 inch.

The results of these measurements are given in Figure 2. (This figure is schematic and not to scale.)

The hardnesses of the various zones are reasonably consistent except for the heat-affected zones of Traverse 2. These hardnesses, particularly on the left side, are significantly lower than at any other area of the heat-affected zone. In these areas, the hardness measurements were taken just at the bottom edge of the cap pass heat-affected zone. On the left side, this location also is directly under the area of the cap or last fill pass where the arc oscillation appears unbalanced. These areas experienced thermal cycles (possibly multiple cycles) that were different from other areas of the heat-affected zone. The different heating-cooling profiles may account for the softer structure.

Microstructure

Photomicrographs of typical weld metal and heat-affected zone areas are shown in Figures 3 through 7.

Figures 3 and 4 are of weld metal. The structure shown in Figure 4 is typical of the fill passes. This weld metal has been "tempered" by subsequent passes. The reheating appears to have caused some precipitation of possible carbides. This change did not result in any significant changes in microhardness.

Figures 5, 6, and 7 are of three areas of a typical fill pass heat-affected zone. The structure in Figure 5 is found adjacent to the fusion line. It is tempered martensite at this location and is very similar to the base metal microstructure. In the cap and root pass heat-affected zones, apparent untempered martensite is found adjacent to the fusion line. An intermediate zone shown in Figure 6 is found in the mid portion of the heat-affected zone while, adjacent to the base metal, a fine-grained microstructure exists (Figure 7).

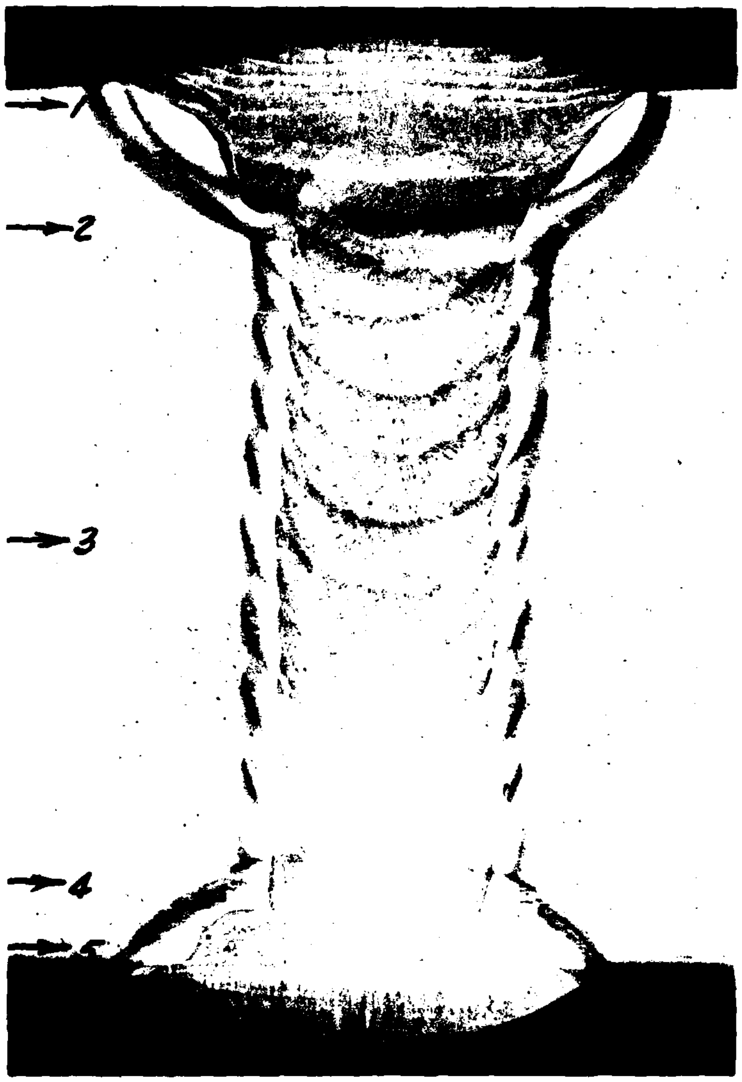
The widths of these three areas of the heat-affected zone vary greatly depending on the location. This is particularly true in the cap and root pass heat-affected zones where significant changes in the widths occur with minor changes in location. Therefore, actual widths were not measured. Generally speaking, the coarse-grained zone varied from about 15 to 30 percent of the heat-affected zone width. The intermediate and fine-grained zones generally were of about the same width and occupied about equally the balance of the heat-affected zone width. If actual widths of these three areas are required for a variety of locations, we can make these measurements.

We hope this provides the information that you need for your report. If you have any questions or need additional information, please let me know.

Best regards,

H. W. Mishler
Metalworking Section

HWM:jrh



2X 3.5% picral - 0.2% nital 3L543

FIGURE 1. PHOTOMACROGRAPH OF NARROW-GAP WELD IN 2- -INCH-THICK HY-100 STEEL

Arrows indicate location of hardness traverses.

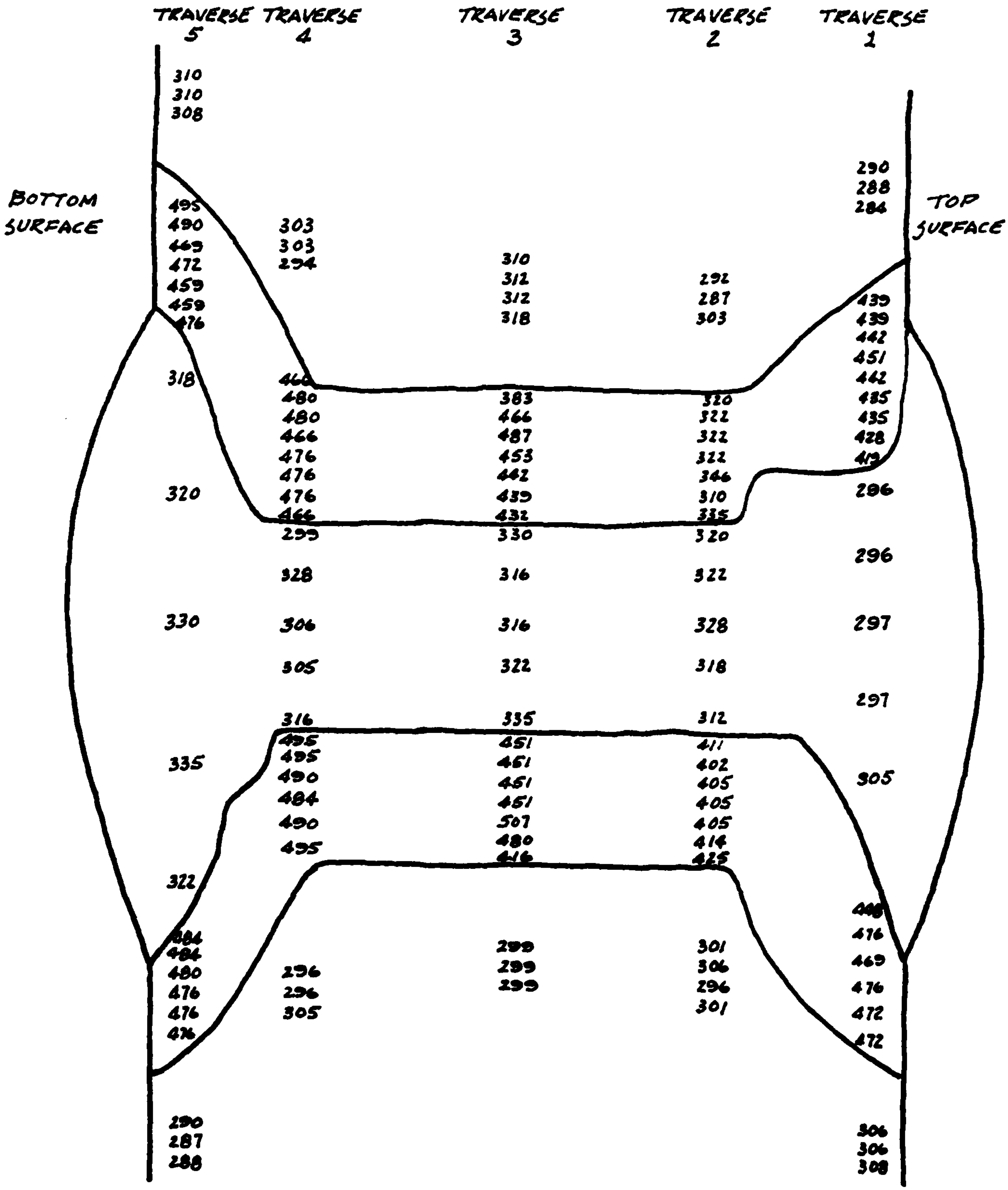
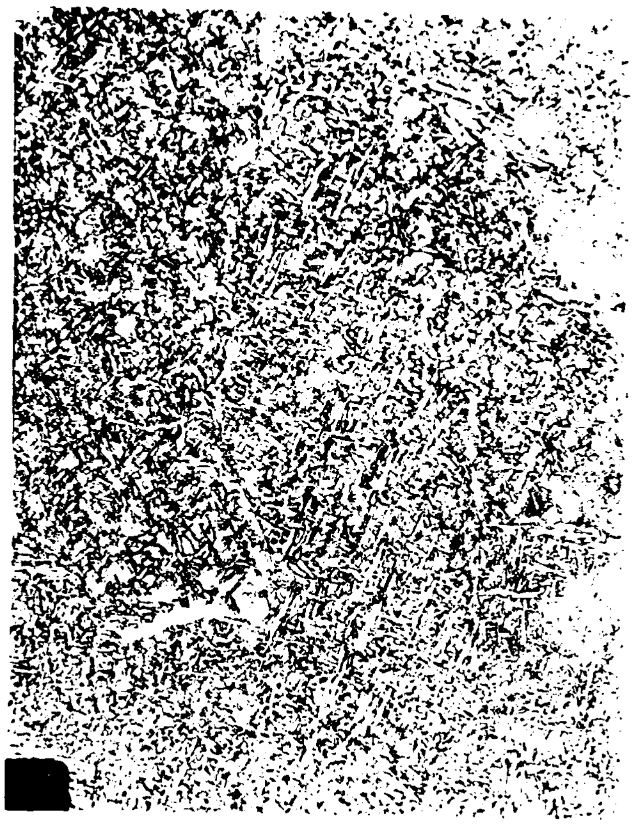
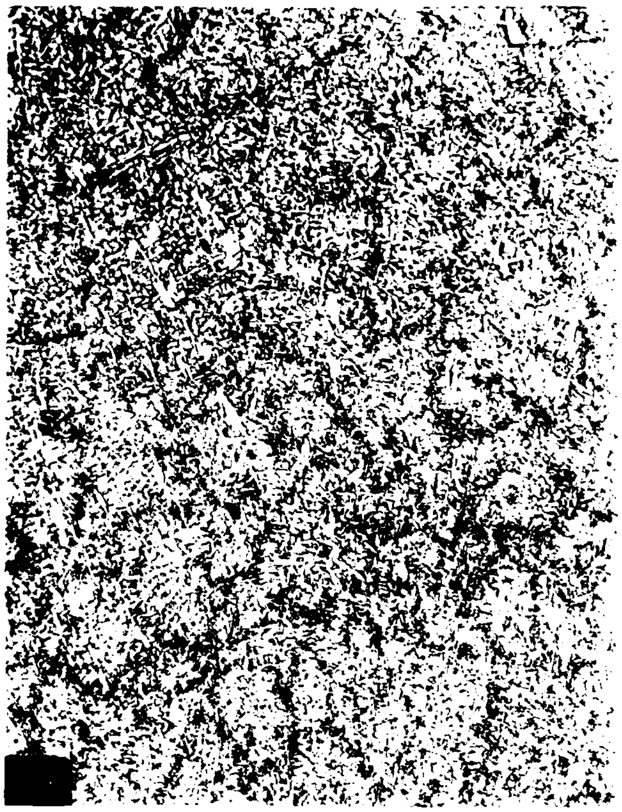


FIGURE 2. KNOOP 500 GM HARDNESS MEASUREMENTS OF NARROW-GAP WELD



500X 3.5% picral - 0.2% nital 3L559

FIGURE 3. PHOTOMICROGRAPH OF CAP PASS WELD METAL OF NARROW-GAP WELD

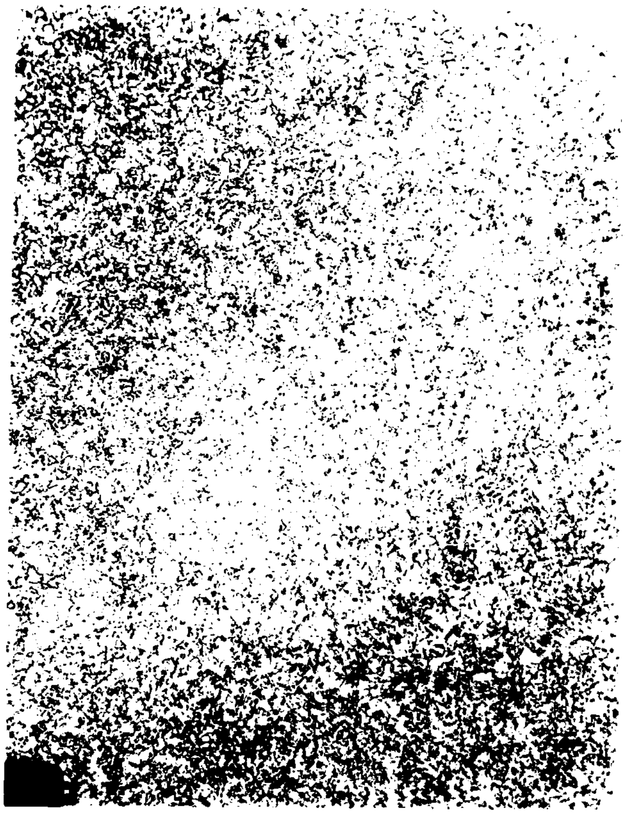


500X 3.5 picral - 0.2 nital 32560

FIGURE 4. PHOTOMICROGRAPH OF TYPICAL FILL PASS WELD METAL OF *NARROW-GAP WELD*

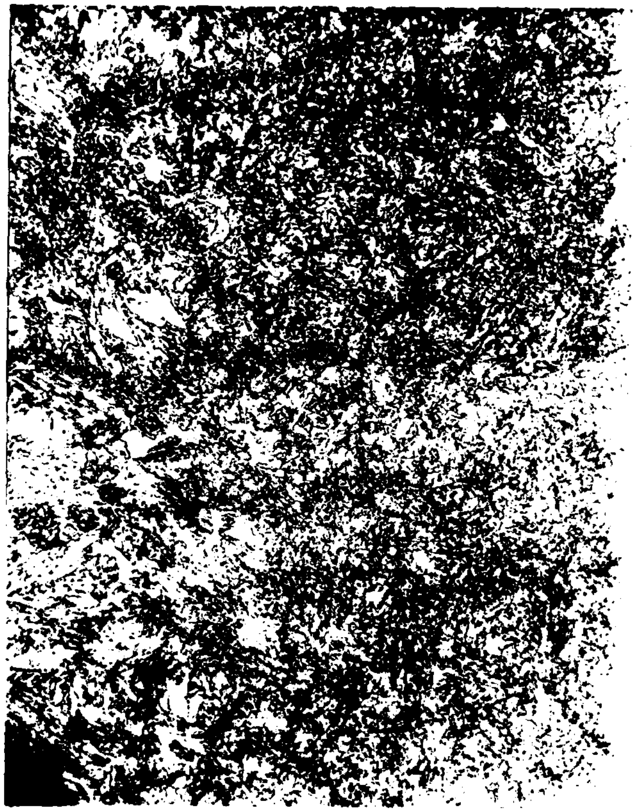
500X 3.5% picral - 0.2% nital 3L561

FIGURE 5. PHOTOMICROGRAPH OF COURSE GRAINED PORTION OF HEAT-AFFECTED ZONE OF NARROW-GAP WELD



500X 3.5% picral - 0.2% nital 3L562

FIGURE 6. PHOTOMICROGRAPH OF INTERMEDIATE GRAINED PORTION OF HEAT-AFFECTED ZONE OF NARROW-GAP WELD



500X 3.5 picral - 0.2 nital 3L563

FIGURE 7. PHOTOMICROGRAPH OF FINE GRAINED PORTION OF HEAT-AFFECTED ZONE OF NARROW-GAP WELD

Base metal microstructure appears on the left.

NAVAL ORDNANCE STATION
LOUISVILLE, KY. 40214

Navy Code No.	845
Type of Test	Crack Starter
Material	HY-Steel
Initial Thickness (in.)	Location A 2.071 Location B 2.063
Remarks:	

	SHOT NUMBER					
	1	2				
Date	9-20-83	9-20-83				
Time elapsed fired	5M 30S	4M 15S				
Stand off Distance (in.)	17"	17"				
Pentolite Charge (lbs.)	24	24				
Temperature of Spec. At Firing (°F) Est.	0°	0°				
Ambient Temperature (°F) (Outdoor)	81°	87°				
Picture Number	845-1-1 845-1-2	845-2-1 845-2-2				
	RESULT OF TEST					
Plate Thk.-Location A	2.000	1.914				
% Reduction In Thickness	3.428	7.580				
Plate Thk.-Location B	2.006	1.909				
% Reduction In Thickness	2.762	7.464				
Depth of Bulge (in.) A B	1.540 1.540	2.655 2.688				

Shot #1: Tear across weld bead at center, enters base metal B side 5/8 inch. Crack across crack starter weld "A" side, TOW ½" Crack across crack starter weld B side TOW ½" long, enters base metal

Shot #2: Tear across weld bead at center extends into base metal A side 5/8", into B side 1". Crack A side across crack starter bead extends 3/4". Crack B side from 2½" left of center to 2" right of center. Tear penetrates deep into weld metal.

NAVAL ORDNANCE STATION
LOUISVILLE, KY. 40214

Navy Code No.	846
Type of Test	Crack Starter
Material	HY-Steel
Initial Thickness (in.)	Location A 2.085 Location B 2.087
Remarks:	

	SHOT NUMBER					
	1	2				
Date	9-20-83	9-20-83				
Time elapsed fired	4M 50S	5M 25S				
Stand off Distance (in.)	17"	17"				
Pentolite Charge (lbs.)	24	24				
Temperature of Spec. At Firing (°F) Est.	0°	0°				
Ambient Temperature (°F) (Outdoor)	81°	87°				
Picture Number	846-1-1 846-1-2	846-2-1 846-2-2				
	RESULT OF TEST					
Plate Thk.-Location A	2.000	1.918				
% Reduction In Thickness	4.076	8.009				
Plate Thk.-Location B	2.010	1.938				
% Reduction In Thickness	3.689	7.139				
Depth of Bulge (in.) A B	1.520 1.540	2.815 2.850				

Shot #1 Tear across weld bead center, enters base metal A side 5/8", B side ½". Crack across crack starter weld A side TOW. Crack across crack starter weld B side TOW. Numerous surface cracks in HAZ, particularly B side.

Shot #2 Tear across weld bead at center extends into base metal A side 1½", into B side 1¼", penetrates deep into weld metal. Crack A side TOW from 2½" left of center to 1¼" right of center (3 3/4 total). Crack B side TOW from 2 3/4" left of center to 1½" right of center (4¼" total).

NAVAL ORDNANCE STATION
LOUISVILLE, KY. 40214

Navy Code No.	847
Type of Test	Bulge
Material	HY-Steel
Initial Thickness (in.)	Location A 2.055 Location B 2.048
Remarks:	

	SHOT NUMBER					
	1	2	3	4		
Date	9-21-83	9-21-83	9-22-83	9-22-83		
Time elapsed fired	6M 20S	5M 45S	5M 35S	5M 45S		
Stand off Distance (in.)	17"	17"	17"	17"		
Pentolite Charge (lbs.)	24	24	24	24		
Temperature of Spec. At Firing (°F) Est.	0°	0°	0°	0°		
Ambient Temperature (°F) (Outdoor)	49°	59°	51°	62°		
Picture Number	847-1-1	847-2-1	847-3-1	847-4-1 847-4-2		
	RESULT OF TEST					
Plate Thk.-Location A	2.016	1.953	1.898	1.824		
% Reduction In Thickness	1.897	4.963	7.639	11.240		
Plate Thk.-Location B	1.992	1.915	1.866	1.796		
% Reduction In Thickness	2.734	6.494	8.886	12.304		
Depth of Bulge (in.) A B	1.455 1.530	2.515 2.605	3.230 3.400	3.730 4.025		

Shot # 1 N.V.C.T.

Shot # 2 N.V.C.T.

Shot # 3 N.V.C.T.

Shot # 4: Crack A side TOW from 2½" left of center to 1" right of center

NAVAL ORDNANCE STATION
LOUISVILLE, KY. 40214

Navy Code No.	848
Type of Test	Bulge
Material	HY-Steel
Initial Thickness (in.)	Location A 2.087 Location B 2/040
Remarks:	

	SHOT NUMBER					
	1	2	3	4		
Date	9-21-83	9-21-83	9-22-83	9-22-83		
Time elapsed fired	6M 15S	6M 05S	5M 45S	5M 40S		
Stand off Distance (in.)	17"	17"	17"	17"		
Pentolite Charge (lbs.)	24	24	24	24		
Temperature of Spec. At Firing (°F) Est.	0°	0°	0°	0°		
Ambient Temperature (°F) (Outdoor)	49°	59°	51°	62°		
Picture Number	848-1-1	848-2-1	848-3-1 848-3-2	848-4-1 848-4-2		
	RESULT OF TEST					
Plate Thk.-Location A	2.032	1.961	1.928	1.840		
% Reduction In Thickness	2.635	6.037	7.618	11.835		
Plate Thk.-Location B	1.997	1.969	1.867	1.780		
% Reduction In Thickness	2.107	3.480	8.480	12.745		
Depth of Bulge (in.) A	1.515	2.480	3.235	3.880		
Depth of Bulge (in.) B	1.605	2.625	3.355	4.030		

Shot # 1 N.V.C.T.

Shot # 2 N.V.C.T.

Shot # 3: Crack B side TOW 3½" left of center. Appears to be weld reinforcement or weld patch coming loose from base metal.

(Tack weld location)

Shot # 4: Crack A side TOW from 4" left of center to 1" right of center. Crack B side TOW 3½" left of center is now 2½" long. Piece is almost "popped out".

NAVAL ORDNANCE STATION
LOUISVILLE, KY. 40214

Navy Code No.	849
Type of Test	Bulge
Material	HY-Steel
Initial Thickness (in.)	Location A 2.079 Location B 2.080
Remarks:	

	SHOT NUMBER					
	1	2	3	4		
Date	9-21-83	9-21-83	9-22-83	9-22-83		
Time elapsed fired	7M 05S	5M 35S	5M 40S	5M 35S		
Stand off Distance (in.)	17"	17"	17"	17"		
Pentolite Charge (lbs.)	24	24	24	24		
Temperature of Spec. At Firing (°F) Est.	0°	0°	0°	0°		
Ambient Temperature (°F) (Outdoor)	49°	59°	51°	62°		
Picture Number	849-1-1	849-2-1	849-3-1 849-3-2	849-4-1 849-4-2		
	RESULT OF TEST					
Plate Thk.-Location A	2.021	1.961	1.854	1.827		
% Reduction In Thickness	2.789	5.675	10.822	12.127		
Plate Thk.-Location B	2.010	1.933	1.870	1.807		
% Reduction In Thickness	3.365	7.067	10.096	13.125		
Depth of Bulge (in.) A B	1.570 1.600	2.590 2.580	3.525 3.455	4.045 4.000		

Shot # 1 N.V.C.T.

Shot # 2 N.V.C.T.

Shot # 3: Shallow crack B side TOW 1 3/4" left of center. Appears to be reinforcement bead coming loose from base metal. (Tack weld location)

Shot # 4: Crack B side TOW extends center to 2" left of center.

NAVAL ORDNANCE STATION
LOUISVILLE, KY. 40214

Navy Code No. 850

Type of Test Bulge

Material HY-Steel

Initial Thickness (in.) Location A 2.080 Location B 2.079

Remarks:

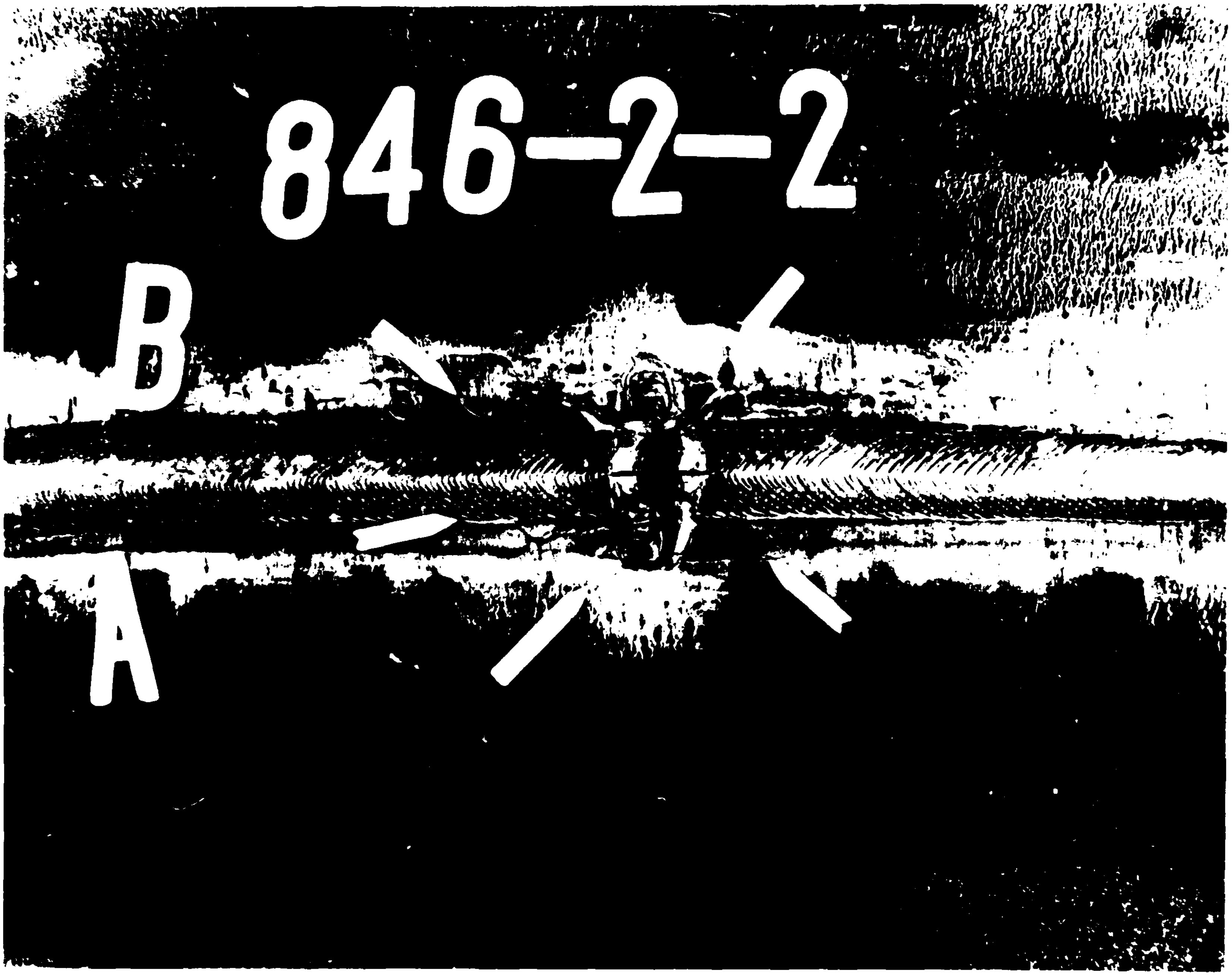
	SHOT NUMBER					
	1	2	3	4		
Date	9-21-83	9-21-83	9-22-83	9-22-83		
Time elapsed fired	5M 55S	5M 35S	4M 50S	5M 30S		
Stand off Distance (in.)	17"	17"	17"	17"		
Pentolite Charge (lbs.)	24	24	24	24		
Temperature of Spec. At Firing (°F) Est.	0°	0°	0°	0°		
Ambient Temperature (°F) (Outdoor)	49°	59°	51°	62°		
Picture Number	850-1-1	850-2-1	850-3-1 ~~850-3-2~~	850-4-1 850-4-2		
	RESULT OF TEST					
Plate Thk.-Location A	2.011	1.961	1.890	1.836		
% Reduction In Thickness	3.317	5.721	9.134	11.730		
Plate Thk.-Location B	2.015	1.929	1.843	1.764		
% Reduction In Thickness	3.078	7.215	11.351	15.151		
Depth of Bulge (in.) A B	1.555 1.585	2.510 2.570	3.405 3.480	3.910 4.020		

Shot # 1 N.V.C.T.

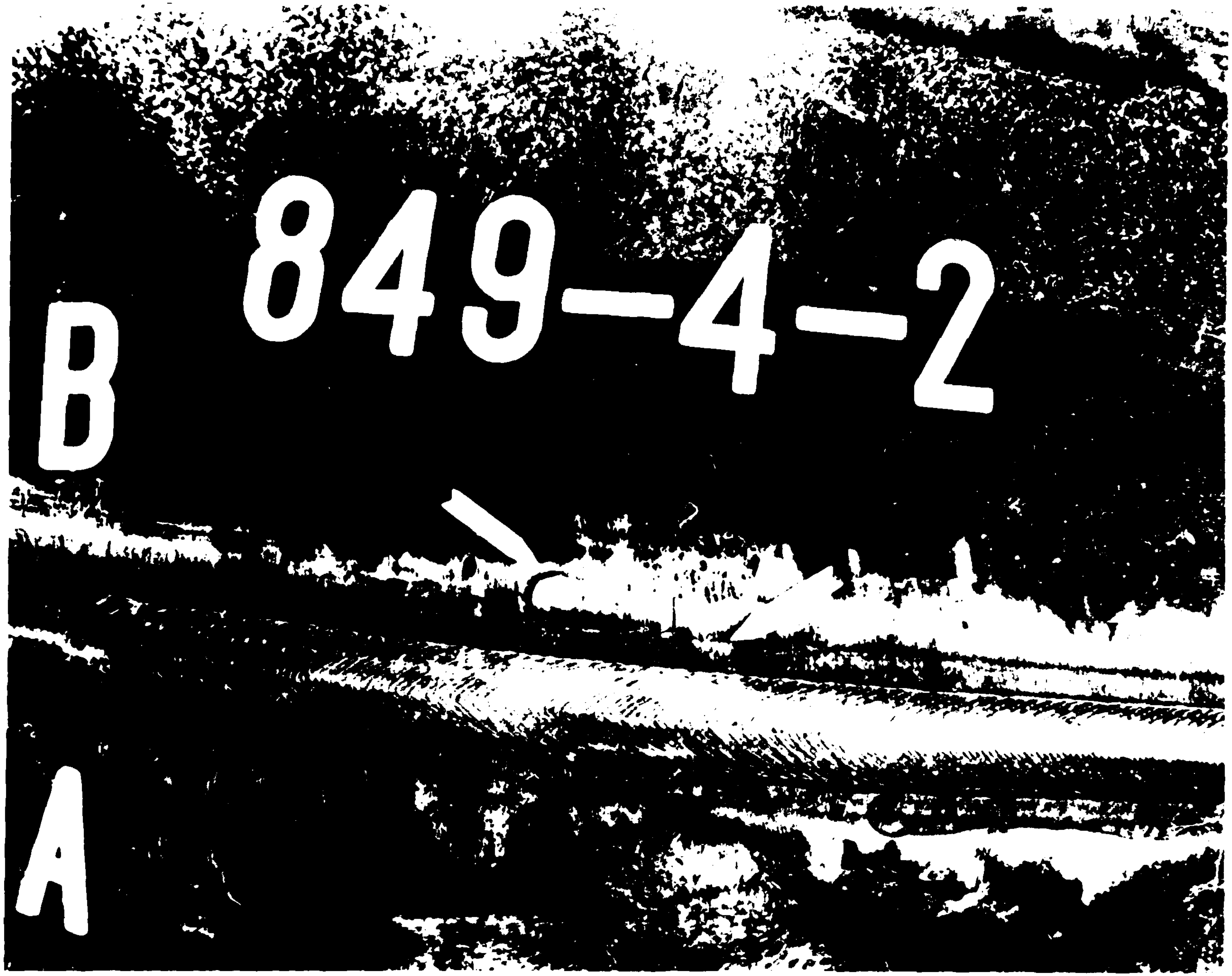
Shot # 2 N.V.C.T.

Shot # 3: Crack A side TOW from 1 3/4" left of center to 2" right of center. Crack B side TOW from 2¼" left of center to 1" right of center.

Shot # 4: Crack A side TOW from 3½" left of center to 2½" right of center (6" total). Crack B side TOW from 3" left of center to 3" right of center.



CRACK STARTER SAMPLE NO. 846 AFTER 2 SHOTS



EXPLOSION BULDGE SAMPLE NO. 849 AFTER 4 SHOTS

10